NASA CR-
147560

Ku BAND LOW NOISE
PARAMETRIC AMPLIFIER

REPORT NO. C362-1

MARCH 1976

FINAL REPORT ON CONTRACT NAS9-14586

PREPARED FOR
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Lyndon B. Johnson Space Center
Houston, Texas 77058

AIL a division of CUTLER-HAMMER
DEER PARK, LONG ISLAND, NEW YORK 11729

TABLE OF CONTENTS

TABLE OF CONTENTS (cont)

LIST OF ILLUSTRATIONS

LIST OF TABLES

I. INTRODUCTION

A low noise, K_u-band, parametric amplifier (paramp) has been developed under NASA Contract NAS 9-14586. The unit described herein is a spacecraft-qualifiable, prototype, parametric amplifier for eventual application in the Shuttle Orbiter. The amplifier was required to have a noise temperature of less than 150 K. A noise temperature of less than 120 K at a gain level of 17 dB was achieved. The 3-dB bandwidth required for this program is 50 MHz. A 3-dB bandwidth in excess of 350 MHz was attained, while deviation from phase linearity of about $\pm$ 1 degree over 50 MHz was achieved. (The design requirement was $\pm$ 5 degrees over 50 MHz.) The paramp operates within specification over an ambient temperature range of -5°C to $+50^{\circ}$C. Figure 1 shows the parametric amplifier system.

The following sections give the details of all of the performance requirements and the operation of the K_u-band parametric amplifier system. The final test results are also given.

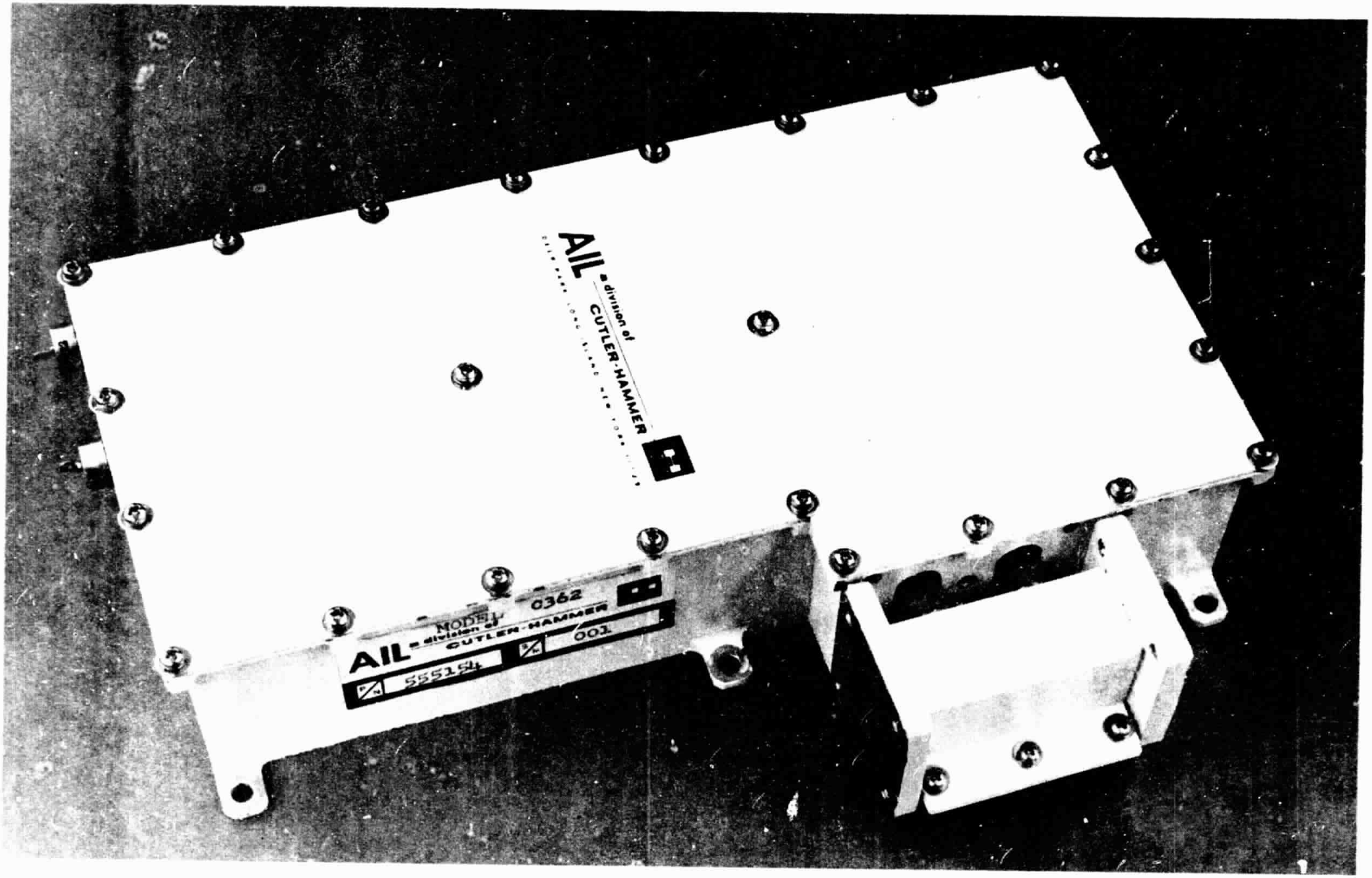


Figure 1. K_u-Band Parametric Amplifier System

II. CONTRACT PERFORMANCE REQUIREMENTS

The major performance specifications defined by the contract are as follows:

2.1 NOISE TEMPERATURE

The parametric-amplifier noise temperature shall not exceed 150 K over the entire instantaneous bandwidth. The system noise temperature shall be measured by means of the hot and cold input termination method. The specified noise temperature shall not include any second-stage noise contributions.

2.2 CENTER FREQUENCY AND BANDPASS

The bandpass center frequency shall be 13.775 GHz. The 3-dB bandpass shall cover the 13.750 to 13.800 GHz frequency range.

2.3 BANDWIDTH AND RIPPLE

The instantaneous bandwidth between the 3-dB points shall be 50 MHz minimum at the specified gain. The gain ripple shall not exceed 1 dB peak-to-peak over the bandwidth, except at the corners of the bandpass response.

2.4 GAIN

The gain shall be 17 dB minimum over the bandwidth except at the corners of the bandpass response.

2.5 GAIN STABILITY

2.5.1 Gain Stability Versus Temperature

The gain shall remain stable to within $\pm$ 1 dB over an ambient temperature range of $-5^{\circ}C$ to $+50^{\circ}C$.

2.5.2 Gain Stability Versus Time

The gain shall remain stable to within $\pm$ 1.0 dB over an 8-hour period at an ambient temperature of $20^{\circ}C \pm 5^{\circ}C$.

2.6 INPUT VSWR

The amplifier input VSWR shall not exceed 1.5:1 over the entire instantaneous bandwidth. This specification shall apply with the parametric amplifier operating at the specified gain of 17 dB. The input VSWR shall remain within specifications with the paramp output terminated in a load having a return loss of 10 dB or higher.

2.7 OUTPUT VSWR

The output VSWR shall not exceed 1.75:1 over the entire instantaneous bandwidth with the parametric amplifier operating at the specified gain of 17 dB.

2.8 DYNAMIC RANGE

The signal compression shall be less than 1.0 dB for input signal levels up to -50 dBm.

2.9 PHASE LINEARITY

The phase linearity shall be within $\pm$ 5 degrees over the 50 MHz instantaneous bandwidth.

2.10 RF RADIATION AND MAGNETIC SHIELDING

Radiation and magnetic shielding shall be provided, if necessary, to prevent any noticeable degree of interaction from occurring when two completely integrated parametric amplifiers are separated by one-half (1/2) of an inch in the worst case orientation of the two units.

2.11 POWER SUPPLY

A DC-DC converter shall be provided to operate the pump source and to furnish the parametric amplifier bias voltage, if necessary. The power supply shall operate on 28.0 Vdc $\pm$ 4.0 V. The input current shall be limited to a maximum value of 1.0 A. The power supply shall be an integral part of the parametric amplifier.

2.12 SIZE

The design goal for the enclosed volume shall be forty eight (48) cubic inches for the complete integrated parametric amplifier, including the DC-DC power converter. The maximum enclosed volume shall be seventy two (72) cubic inches.

2.13 WEIGHT

The design goal for the total weight shall be twenty four (24) ounces for the integrated parametric amplifier, including the DC-DC power converter. The maximum allowed weight shall be forty (40) ounces.

2.14 CONNECTORS

The RF input and output connectors shall be a waveguide type connector.

2.15 TURN-ON AND TURN-OFF

The turn-on and turn-off operations shall be accomplished by the sudden application and removal, respectively, of the DC power supply voltage by means of a switch. The parametric amplifier shall be capable of withstanding such a procedure without damage and without exhibiting any tendency to instability.

2.16 OPERATING ENVIRONMENT

The integrated parametric amplifier will be employed in an earth-orbiting spacecraft. The design of the parametric amplifier and the selection of components shall be such that no basic limitation exists which will prevent the operation of the paramp in a space environment with a space qualified reliability.

III. SYSTEM PERFORMANCE

3.1 MEASURED CHARACTERISTICS

The performance of the K_u-band parametric amplifier during final acceptance, along with the corresponding specifications, are listed in Table 1. A phase linearity measurement was also taken, and its results are included in Table 1.

3.2 ENVIRONMENTAL TESTS

The only environmental testing required for this program was the gain stability performance of the system over the -5°C to +50°C ambient range. The results of this test are shown in Table 2. It can be seen that the gain of the parametric amplifier varied by ± 1.2 dB over the ambient temperature range when tested in standard atmosphere. In the normal operating environment of the paramp, which is in vacuum, the gain stability would be well within the ± 1.0 dB specification. In standard atmospheric pressure, the measured temperature of the Gunn diode oscillator varied 2.0°C over the ambient temperature range. However, when measured in a vacuum, the GDO temperature remained constant over the entire range (-5°C to +50°C). Since the output power of an average GDO of the type used in the K_u-band paramp varies by about 0.03 dB/°C, the power output of the GDO varies by 0.06 dB over the ambient temperature range. The gain of a paramp varies 10 dB for every 1 dB change in pump power; consequently, the paramp gain will then vary ± 0.3 dB (0.6 dB total over ambient temperature range) when operated in the standard atmosphere. This factor, coupled with the elimination of convection losses, will put the gain variation vs ambient temperature performance well within the ± 1.0 dB specification when the unit is operated in a vacuum; its normal environment.

Table 1. Measured Performance of the K_u-Band Parametric Amplifier System

Parameter	Specification	Measured Performance
Noise Temperature	150°K	116.3°K
Center Frequency and Bandpass	13.775 GHz (13.750 to 13.800 GHz)	13.775 GHz (13.62 to 14.00 GHz)
Bandwidth (3 dB) and Ripple	50 MHz with 1 dB or less peak-to-peak ripple	380 MHz with no ripple
Gain	17 dB minimum	17.75 dB minimum
Gain Stability vs Temperature	± 1 dB over ambient temperature range of -5°C to +50°C	± 1.2 dB (measured in standard atmosphere)
Gain Stability vs Time	± 1.0 dB over an 8-hour period at room temperature	-0.2 dB over a 14-hour period
Input VSWR	1.5:1	< 1.3:1
Output VSWR	1.75:1	< 1.3:1
Dynamic Range	Less than 1.0 dB for input levels up to -50 dBm	-38 dBm
Phase Linearity	± 5 degrees	± 1 degree
RF Radiation and Magnetic Shielding	No effect when two units are spaced by 1/2 inch	Not tested
Power Supply	Integral power supply operating on 28 Vdc with maximum current of 1.0 A	Operates on 28 Vdc with maximum current of 0.9
Size	48 cubic inch design goal 72 cubic inch maximum	64.8 cubic inches
Weight	24 ounce design goal 40 ounce maximum	38.7 ounces
Connectors	Waveguide type	WR-62 waveguide

Table 1 (continued)

Parameter	Specification	Measured Performance
Turn-on and Turn-off	Sudden application and removal of dc power supply voltage by means of a switch	Complied
Operating Environment	Space vacuum	Space vacuum
EMC	EMC requirements of SL-E-0002 and MIL-STD-462 Notice 1 and 2 CE01, CE03, TT01, C501, C502, and C506	Designed toward specifications, but no testing required

Table 2. System Gain vs Ambient Temperature
(Measured in Standard Atmosphere)

Temperature (°C)	Gain (dB)
22	18.25
-5	19.50
50	17.1

IV. PHYSICAL PARAMETERS

4.1 SIZE

The enclosed volume of the K_u-band parametric amplifier system is 64.8 cubic inches (1061.4 cubic centimeters). This is within the maximum allowable volume, which is 72 cubic inches (1179.9 cubic centimeters). Since the electronics circuity contains several large discrete components, the design goal of 48 cubic inches (786.6 cubic centimeters) was not attained. Although extensive miniaturization techniques are applicable, they were not within the scope of the present funding.

4.2 WEIGHT

The weight of the K_u-band parametric amplifier system, including waveguide-to-coax transitions and power supply, is 38.7 ounces (1097 grams). This weight is within the allowed maximum weight of 40 ounces (1133 grams). Major items where weight saving techniques might apply are in the input power filtering circuitry and RF transmission lines. The inclusion of an input choke (A1-L1 in Figure 7), necessary for EMI suppression, accounts for 3.2 ounces (91.4 grams) alone. The waveguide-to-coax transitions and associated bracketry also contribute 2.8 ounces (80 grams) to the weight of the system.

V. RF SUBASSEMBLY

5.1 BLOCK DIAGRAM DESCRIPTION

The K_u-band parametric amplifier is small and compact. It consists of several modules that integrate together to operate as a sophisticated system. This section describes operation at both the system and module levels.

The integrated K_u-band parametric amplifier was built for use as part of the communication equipment of the Shuttle Orbiter. It provides low noise amplification of the RF signals received at 13.775 GHz. The signal received by the antenna on the space vehicle is routed into the K_u-band parametric amplifier where the signal level at the gain center-frequency location is increased by a minimum of 17 dB. The amplified signal is then routed from the parametric amplifier system to the next function of the communication equipment in the space vehicle.

The block diagram of the K_u-band parametric amplifier is shown in Figure 2.

Signals routed from the receiving antenna enter the parametric amplifier system at the input port, W1. The signal received at that port is routed by the single junction circulator through the single tuned signal circuit into the waveguide balanced varactor mount where the signal is amplified because of the energy transfer from the pump source due to the nonlinear reactance of the varactors. The amplified signal then re-enters the single junction circulator via the single tuned signal circuit and is finally routed to the output port. The circulator terminates any reflected signal entering the RF output port.

The DC blocking terminations (DC blocked RF termination and bias inject RF termination) prevent the varactor bias current from flowing through the circulator terminations and prevents any DC voltage potential connected to the RF ports from damaging the varactors.

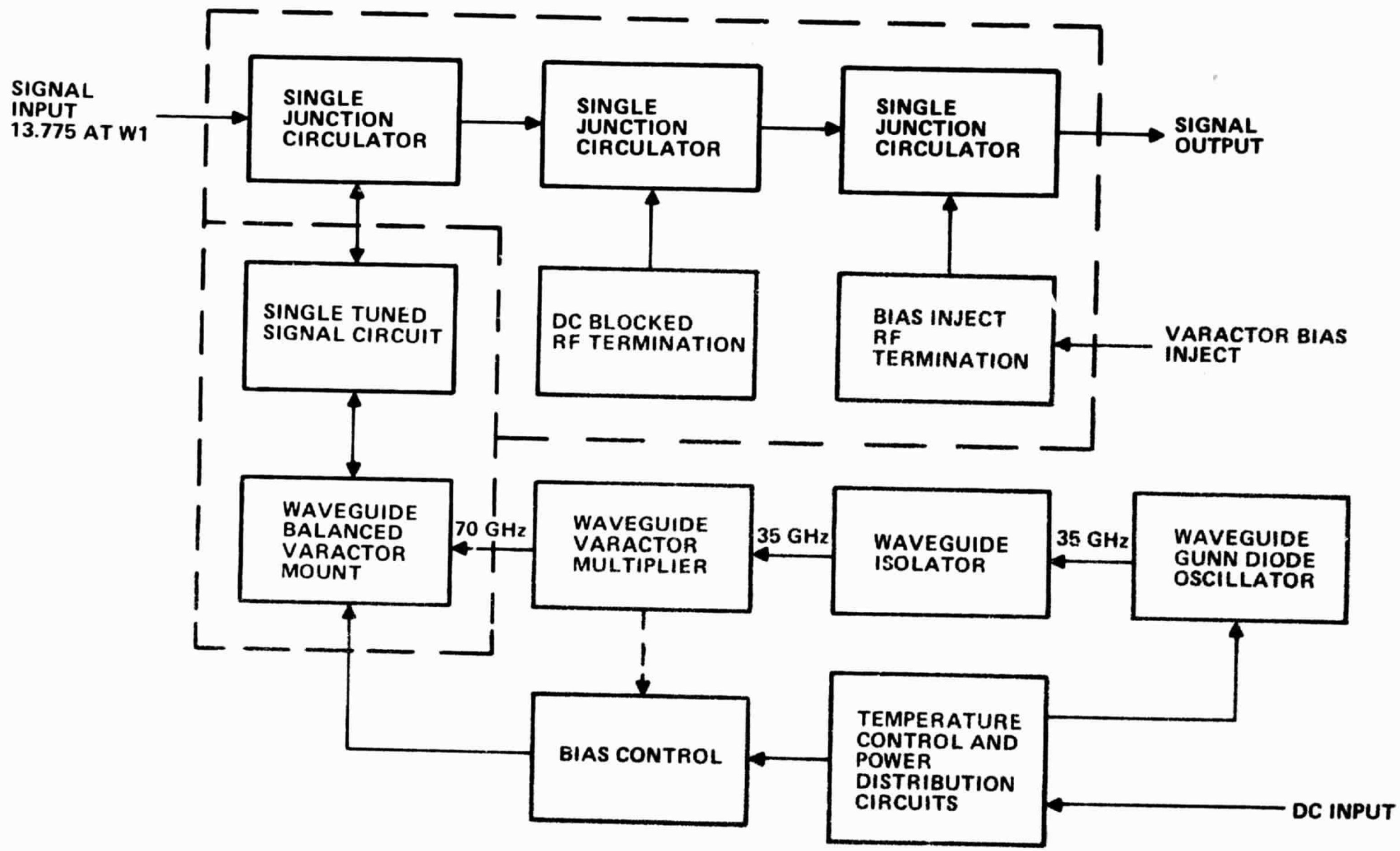


Figure 2. Integrated K_u-Band Parametric Amplifier (RF Subassembly), Block Diagram.

The waveguide Gunn diode oscillator (GDO) is the pump source. It generates RF energy at a frequency of 35 GHz. The RF energy passes through the waveguide isolator and encounters a frequency doubler (waveguide varactor multiplier) which doubles the fundamental pump frequency to 70 GHz. The doubler also produces a rectified, self-bias which can be used to bias the varactors of the paramp mount, if desired.

The temperature control and power distribution maintains a steady temperature of $38^{\circ}C \pm 2^{\circ}C$ at the GDO. This enables the unit to maintain constant gain over the required ambient temperature range.

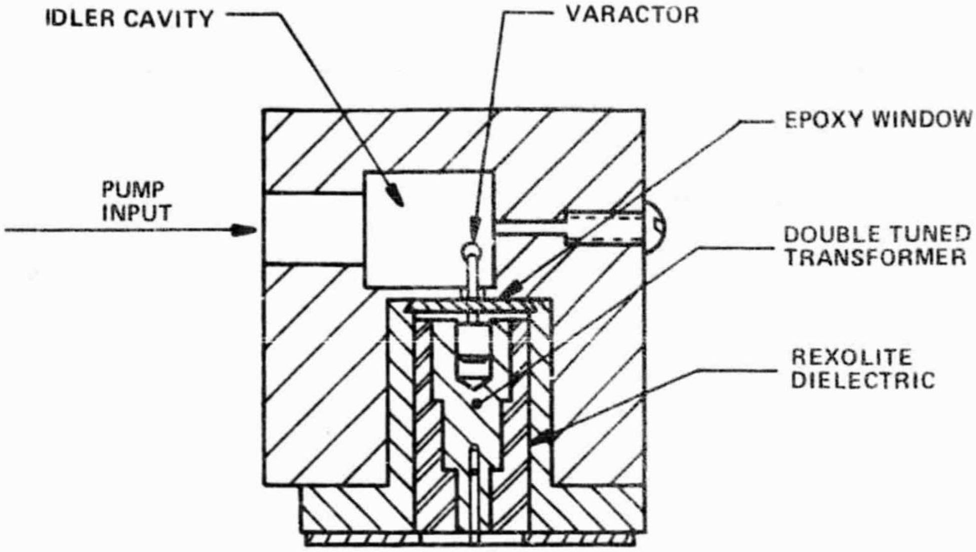
The signal circuit transformer, together with the circulator, the balanced varactor pair in the varactor cavity and the tuning inductance, accomplishes the required broadbanding of the signal circuit.

The following sections describe in some detail the operation of each subassembly component.

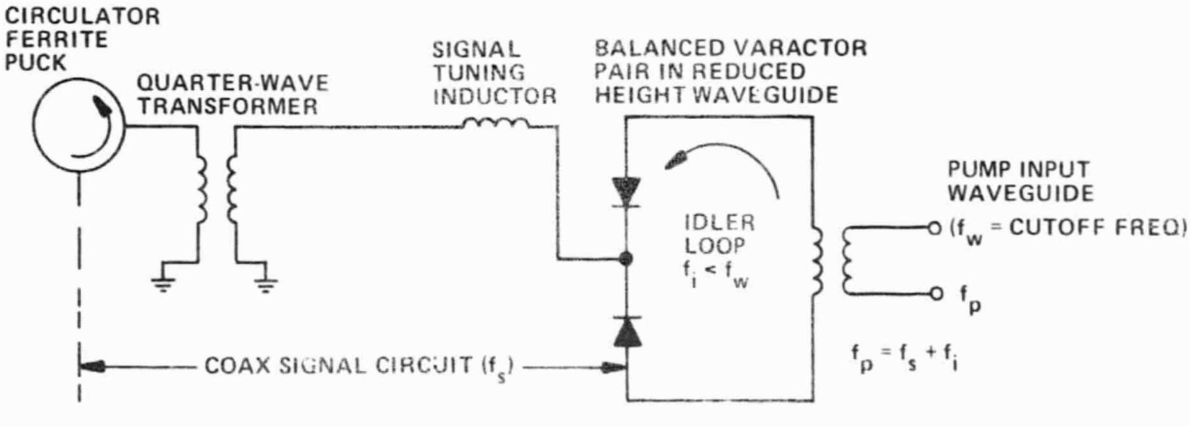
5.2 PARAMETRIC AMPLIFIER MOUNT

The parametric amplifier mount is an electroformed cavity which contains two varactor diodes in a balanced configuration. A diagram of the mount and an equivalent circuit are shown in Figure 3. The two diodes are situated in a section of reduced height waveguide, with the signal circuit tuning inductance sandwiched between them.

The idler circuit is completed by a "cast-in" short circuit located 0.020 inch behind the diodes. Tuning adjustment on the idler circuit, if necessary, is accomplished in steps by widening a cutoff circular aperture in the short. There is a section of waveguide (0.94 inch wide) which is cut off at the idler frequency. This prevents the idler power from propagating down the pump waveguide. This same section also serves as a pump circuit matching transformer.



A. CUT AWAY VIEW OF PARAMP MOUNT



B. EQUIVALENT CIRCUIT OF PARAMP MOUNT

Figure 3. Amplifier Mount and Equivalent Circuit

The signal tuning circuit begins with a 0.0005 x 0.017 inch flipper which is welded to a stud that is embedded in an epoxy window. The broadbanding signal transformers are then screwed onto the opposite end of this stud. This technique allows for changing the signal circuit transformers without putting pressure or strain on the diodes.

Finally, the paramp mount is integrated to the circulator by a special spring contact inserted into the transformer. This spring then gives a pressure contact to the center strip of the circulator.

5.3 VARACTOR DIODES

The key factors in the operation of the paramp mount and the pump frequency doubler are the varactor diodes.

Over the past 16 years the Central Research Group of AIL has been engaged in varactor research. The goal has been to make varactors that have very high cutoff frequencies and at the same time have very low parasitic elements. Presently we believe that a representative equivalent circuit for the varactors as we now mount them in waveguide is as shown in Figure 4. The values of cutoff frequency obtained experimentally compare well with the theoretical calculations.

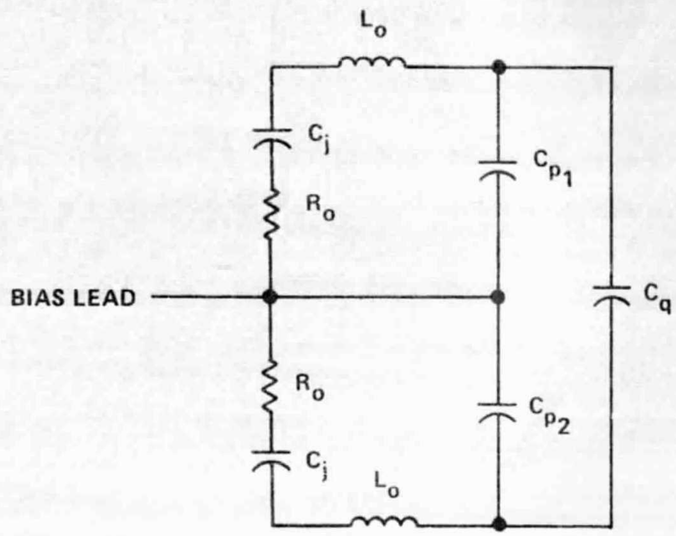
Representative values for the elements of the circuit are:

$$L_S = 1 \times 10^{-10}\ H$$

$$C_P = 0.03\ pF$$

$$F_{CO} \geq 600\ GHz$$

Since varactors of the type described in the preceding paragraphs are being used on programs at AIL, in both the Central Research Group and the Applied Electronics Division, environmental specifications have been a concern. These high cutoff frequency GaAs unsealed varactors are apparently impervious to deterioration when subjected to normal laboratory ambient conditions. Unsealed



WHERE: C_j IS THE JUNCTION CAPACITANCE

L_o IS THE SERIES INDUCTANCE

R_o IS THE SERIES RESISTANCE

C_{p_1}, C_{p_2} ARE STRAY CAPACITANCES RESULTING FROM THE METALIZED LANDS

C_q IS STRAY CAPACITANCE RESULTING FROM THE UNMETALIZED QUARTZ

Figure 4. Equivalent Circuit of Balanced Varactor Pair.

units have operated for several years, withstanding temperature cycling from 15 to 253°C in cryogenic amplifier configurations many times, without any discernible change in operating characteristics. Representative units have undergone the following quantitative and qualitative tests:

a. A nonepitaxial GaAs diode chip was mounted on an unsealed transistor header and characterized on 1 June 1961. This unit has been stored in an open lab environment and at approximately yearly intervals its I versus V characteristics are checked.

b. Ten units successfully passed the following tests with no discernible changes in C versus V and I versus V characteristics:

1. Thermal Shock. Temperature cycling from -65 to 100°C with the unit held at each extreme for 1 hour. Units were subject to five cycles per MIL-STD-200, Method 107, test condition B.
2. High-Temperature Thermal Soak. High temperature reverse bias test. Reverse bias of 80-percent breakdown applied for 96 hours at 100°C.
3. Operation at 50 mA forward current at 25°C for 96 hours.
4. Two units were maintained at 92-percent relative humidity and 30°C for 72 hours with no change in I versus V characteristics.
5. Two units of a more rudimentary design have been installed in a low-noise parametric amplifier for the Signal Corps and have been operative for several years.

Many other units fabricated as long as six years ago show identical characteristics when checked. GaAs varactors may or may not have a natural passivation. In any event, our experience indicates that these varactors do not deteriorate in normal ambients over a wide temperature range.

5.4 CIRCULATOR

The five-port unit (Figure 5) consists of three conventional ferrite Y-junctions. The ferrite discs and impedance transformers are sandwiched between the stripline center conductor and ground planes. Each circulator junction includes a high-dielectric quarter-wave impedance transformer that matches the junction impedance level to 50 ohms. The characteristic impedance of the quarter-wave inter-junction connecting lines is chosen to provide an optimum pole impedance match between the adjacent interconnected junction ports.

The DC magnetic biasing field is provided by permanent magnets embedded into both ground planes, directly above and below the ferrite junctions. For highly reliable electrical performance, an extremely stable magnetic biasing field is required. This criterion is met by using magnets made of cobalt samarium; an extremely stable material. In addition, sensitivity to external fields is reduced by confining the magnetic field in a high permeability steel yoke.

The DC bias for the paramp varactors is injected through a bias inject termination which is built at AIL. The remaining termination also has a DC block to prevent the varactor bias from being shorted to ground. DC blocks are not required on the signal input and output because coax-to-waveguide adapters are employed.

5.5 PUMP SOURCE

5.5.1 Basic Considerations

To achieve a noise temperature less than 150 K, a pump frequency of 70 GHz is required. An IMPATT oscillator could be employed as a pump source at 70 GHz. However, this oscillator is not considered ideal for use as a pump source for a paramp because of noise considerations.

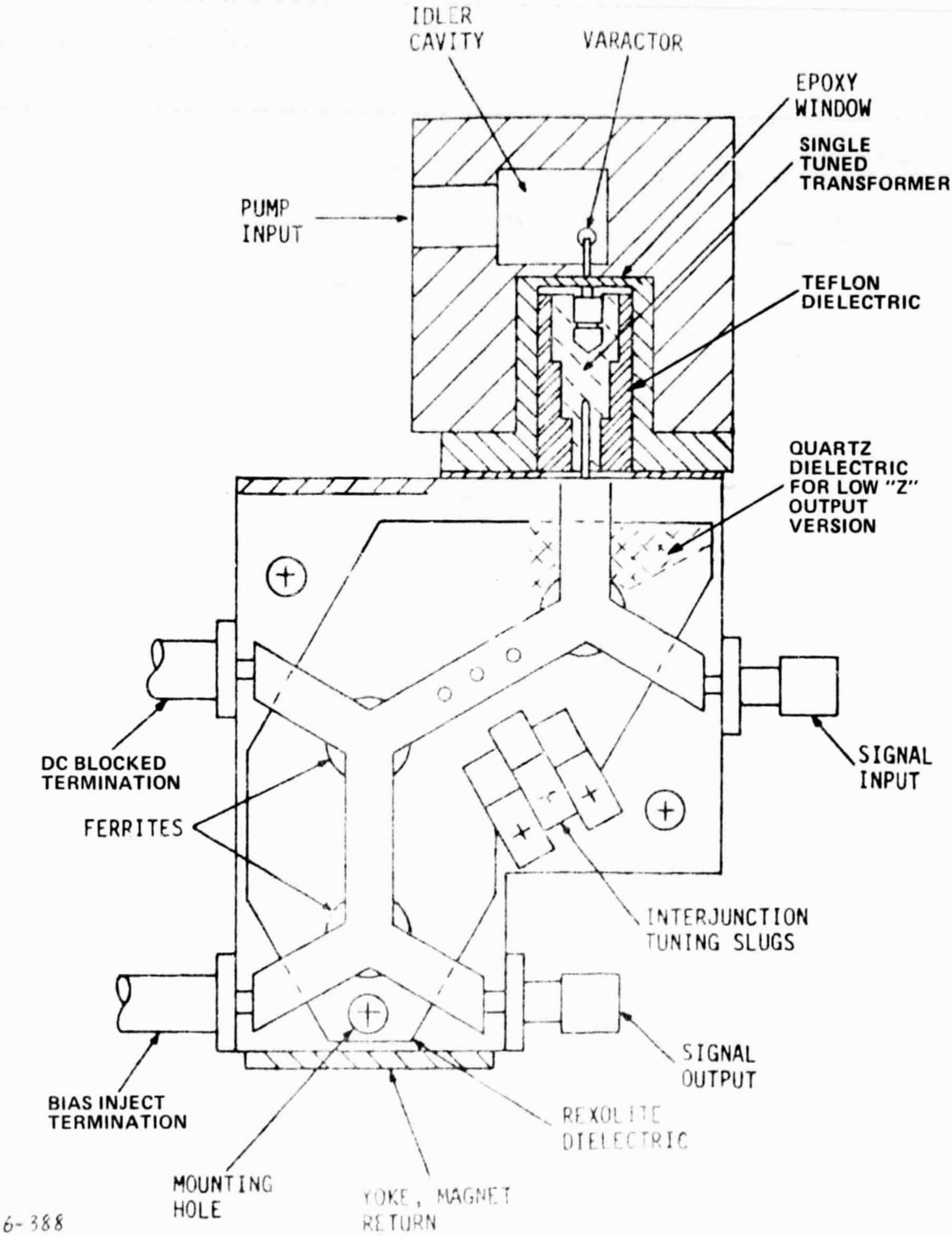


Figure 5. Five-Port Circulator Integrated With Paramp

Since the noise of a pump source can be considered as a random fluctuation in instantaneous pump power, the varactor capacitance will fluctuate accordingly. Because of this, the pump noise is downconverted into the signal domain, thereby degrading the tangential sensitivity of the amplifier. This loss of sensitivity is greatly enhanced in the presence of a strong interfering signal.

For this reason, a Gunn-effect diode oscillator, which is less noisy, was chosen as a pump source. Unfortunately a fundamental oscillator at 70 GHz, giving sufficient output power to drive the varactors in the paramp, is not available. Therefore a 35-GHz GDO and a frequency doubler have been employed to generate the required 70 GHz.

5.5.2 Gunn Diode Oscillator

The pump source is a 35-GHz GDO, manufactured by Varian Associates. It is a high reliability oscillator that can provide 120 mW of power over the frequency range of 34.75 to 35.25 GHz. This GDO has a frequency adjustment screw which is laboratory set and should not be adjusted in the field.

5.5.3 Pump Isolator

The 35-GHz isolator is in WR28 waveguide and is of the T configuration. Its purpose is to act as a stable load for the pump source. All pump energy reflected by the doubler unit (and any second harmonic escaping the doubler mount) will be absorbed in the termination of the isolator.

5.5.4 Pump Frequency Doubler

The pump frequency doubler is a unit which, using a stable varactor diode, accepts the RF pump power supplied by the GDO and doubles it to the required 70 GHz. The efficiency of the doubler unit is about 40 percent. With the GDO delivering greater than 120 mW, at least 36 mW will be available for pumping the paramp diodes. The doubler mount may also serve as a source for the voltage used to bias the varactor diodes of the paramp unit. The incident RF pump power causes a rectified, self-bias to be produced; this is extracted through a bypass network and reduced by a divider network to the proper value for diode bias. A diagram of the doubler mount appears in Figure 6.

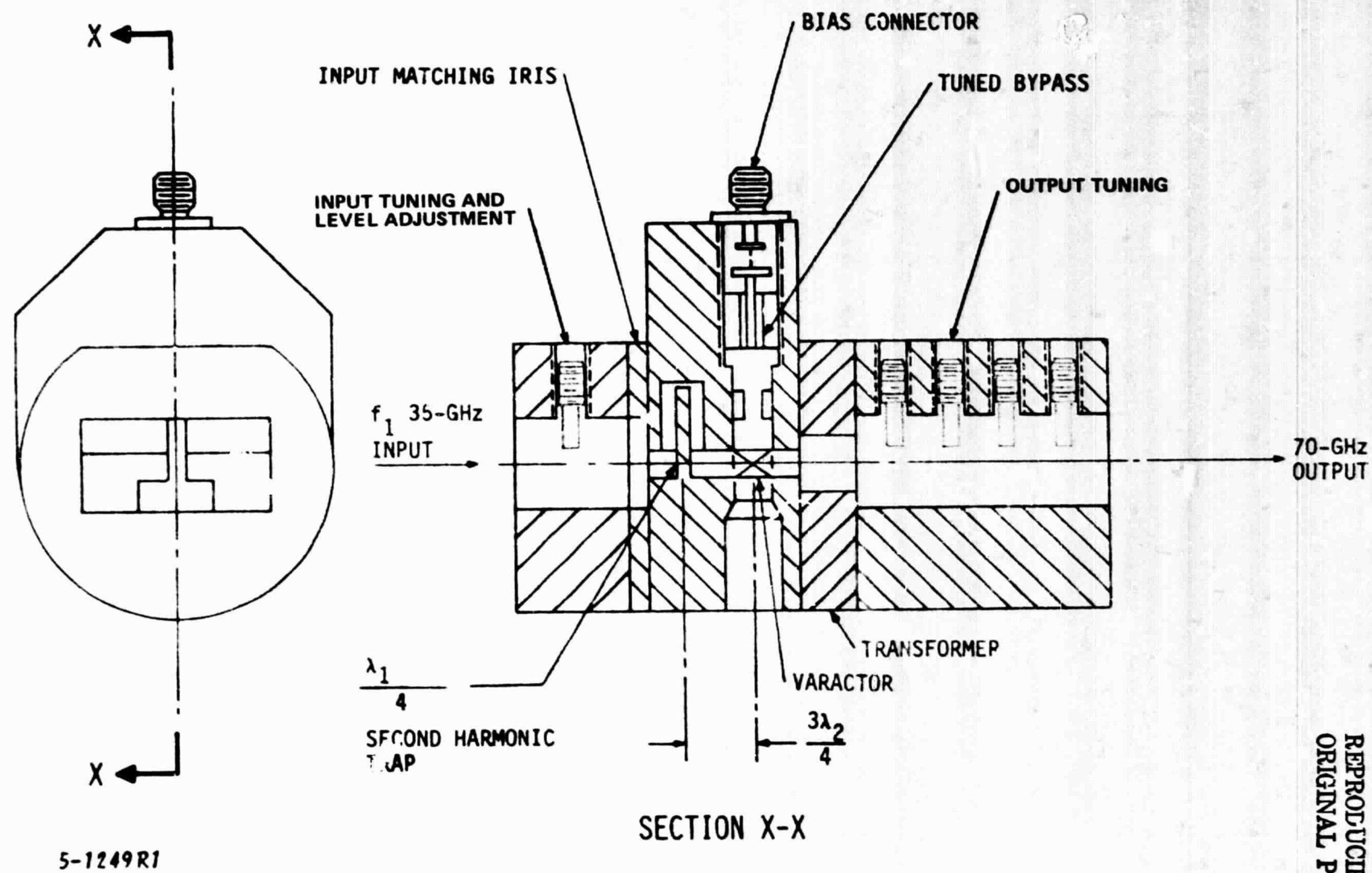


Figure 6. Doubler Mount Diagram.

VI. ELECTRONICS AND CONTROL SUBASSEMBLIES

6.1 FUNCTIONAL DESCRIPTION

The system electronics circuitry serves two functions. The first is to convert the 28-V input supply voltage to desired values, and regulate these voltages to the levels necessary for proper operation of the system. The second function is to control the temperature of the RF components in order to maintain gain stability over the ambient range of $-5^{\circ}C$ to $+50^{\circ}C$. A detailed description of these circuits follow.

6.2 THERMAL STABILIZATION

The biggest factor in gain stability of a paramp is the stability of the pump power source, in this instance a GDO. At a gain level of 18 dB, the paramp gain will vary 1 dB for each 0.1-dB change in pump power level. Therefore the pump power incident on the paramp mount must be held to within $\pm$ 0.1 dB over the ambient range of $-5^{\circ}C$ to $+50^{\circ}C$. Since the output power of a GDO typically varies by 0.05 dB/$^{\circ}$C, the temperature of the GDO cannot be allowed to vary by more than $\pm 2^{\circ}C$.

To hold this level of thermal stabilization, a thermistor is screwed directly into the GDO to monitor its temperature. This data is then routed to a temperature controller circuit (located in the middle compartment with the voltage regulators) which controls a thermoelectric module located beneath the RF component mounting plate, directly under the GDO. The module can heat or cool the RF components depending on the polarity of the applied voltage. The voltage across the thermoelectric module is varied in a proportional manner, rather than by rapid switching, to eliminate excessively rapid variations in temperature and also to increase the reliability of the module.

6.3 POWER SUPPLY

6.3.1 Requirements

A DC-DC converter is necessary to operate the pump source, to furnish the parametric-amplifier bias voltage, and to provide

voltages to bias regulator and thermal control circuits. The power supply shall operate on 28.0 ± 4.0 Vdc, and it shall be limited to a maximum value of 1.0 A. The power supply must be an integral part of the parametric amplifier.

6.3.2 DC-DC Converter

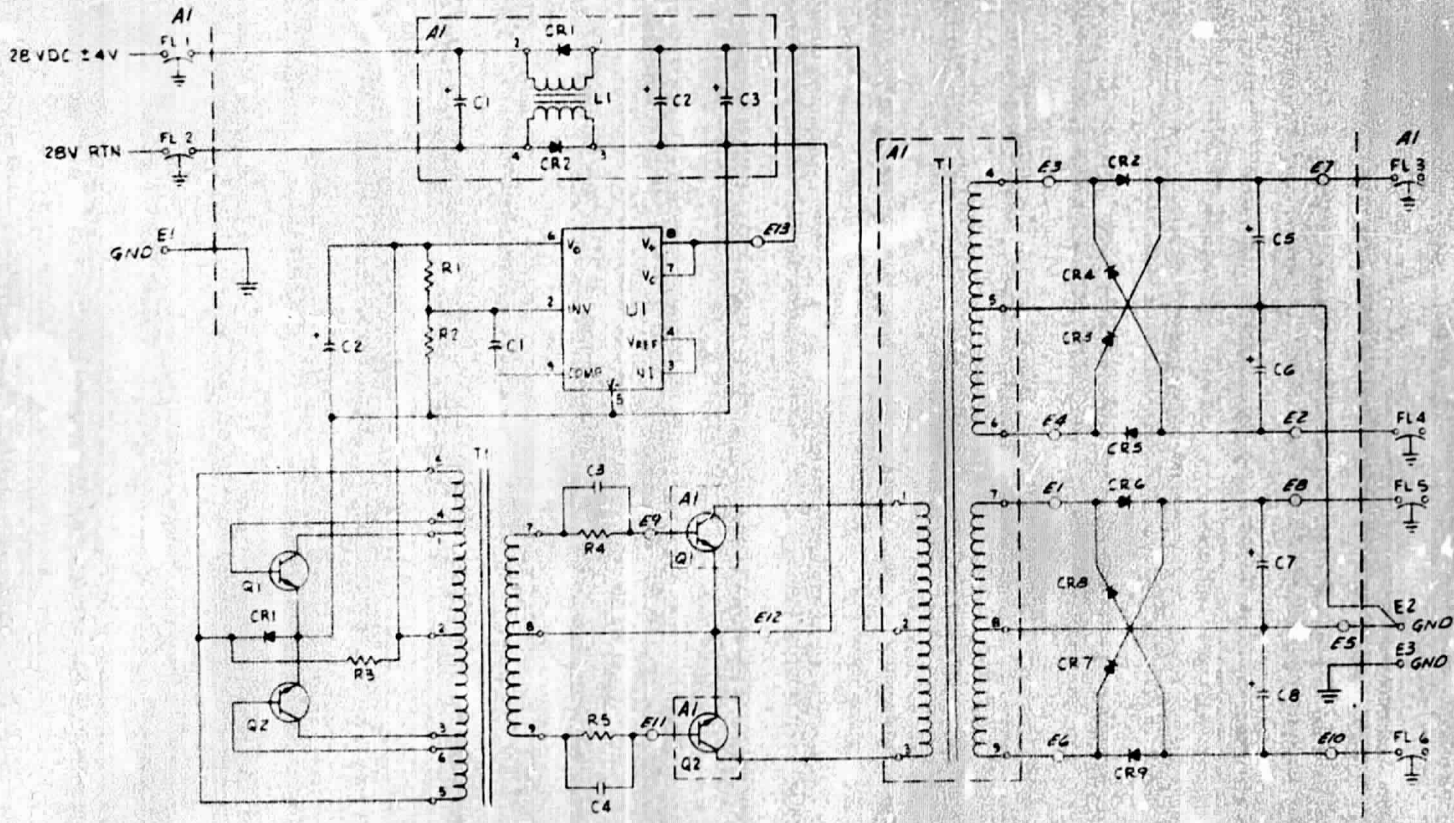
The DC-DC converter circuit incorporates a two-stage inverter operating at approximately 20 kHz, whose outputs are rectified, filtered, and in the case of the GDO and paramp bias outputs, regulated.

The master inverter, consisting of Q1, Q2 and T1 (saturating), provides the drive power at the proper frequency to the power or slave inverter (see Figure 7). This second stage consists of A1Q1, A1Q2 and nonsaturating A1T1, and generates the proper voltage amplitudes for rectification and filtering to the desired DC levels. This two-stage inverter maximizes efficiency by minimizing power losses in the inverter. The center tapped output windings of A1T1 are followed by a full wave rectifier and capacitor filter. These outputs are then fed, through filtered connectors, into the regulator/temperature control section.

6.3.3 Regulator-Temperature Control Circuits

The heart of the GDO regulator is a linear integrated circuit, U2, which includes a stable reference, comparison and amplifier circuit (see Figure 8). This circuit compares a portion of the GDO output to its internal reference and controls pass transistor A1Q7 to maintain a constant, closely regulated output to the GDO. Operating the integrated circuit input from a higher voltage, low-current boost winding minimizes the voltage and, therefore, power lost across A1Q7. Pass transistor A1Q7 handles the full current output to the GDO of approximately one ampere.

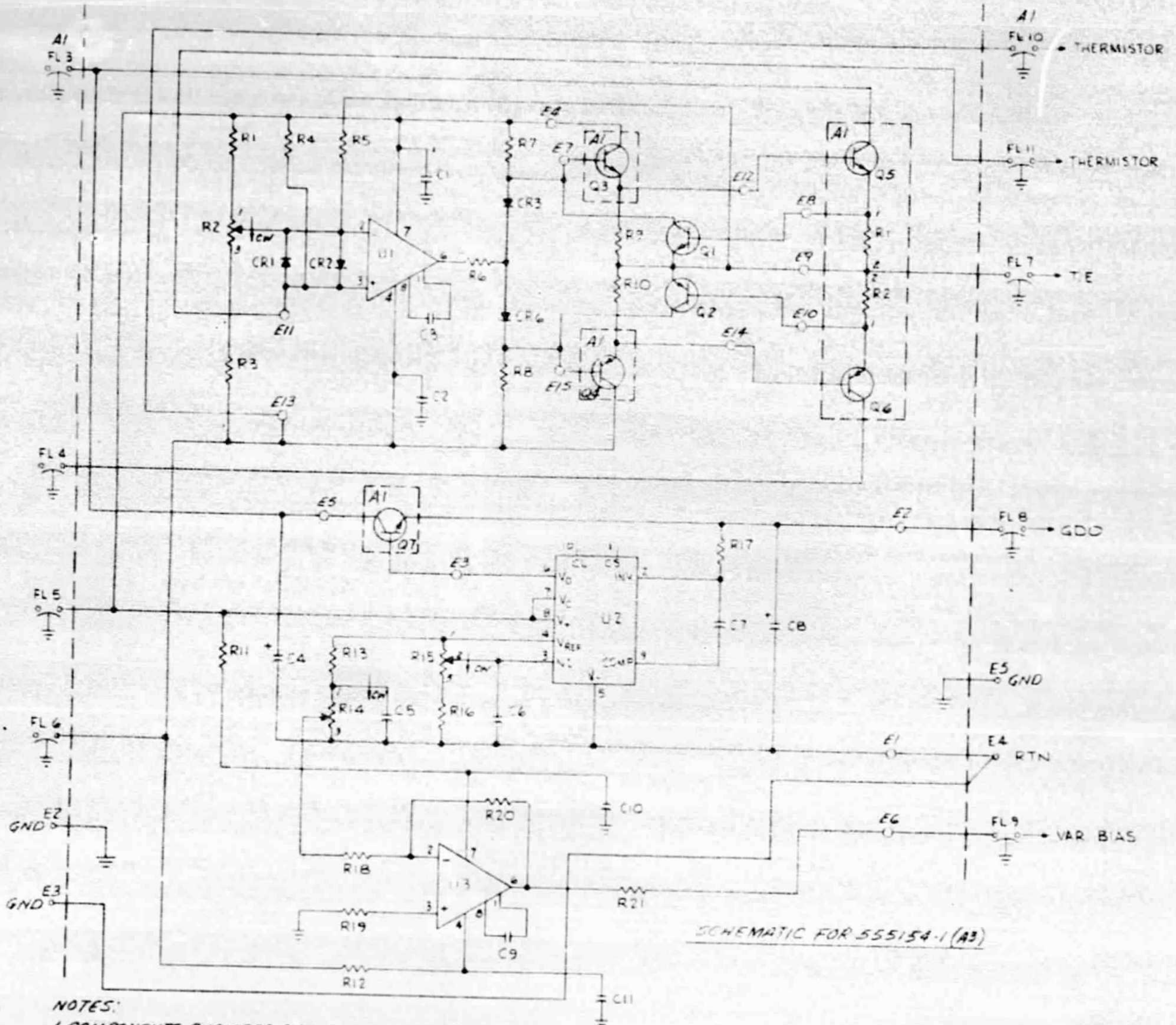
The control circuit for the thermoelectric module consists of operational amplifier U1 and associated circuitry. This circuit arrangement is a complementary push-pull amplifier which provides a bipolar voltage as required to cause the thermoelectric module to heat or cool. Thermistor RT1 is the temperature sensing element



SCHEMATIC FOR 555154-1 (A2)

NOTES:
1. COMPONENTS ENCLOSED BY DOTTED LINES ARE SHOWN FOR REFERENCE, THEY ARE PART OF 555154-1 (A1) ASSEMBLY. THE PART NUMBERS ARE AS FOLLOWS;
C1 & C2 ARE CSR13H106K
C3 IS CSR13K106K
T1 IS POLYPHASE, P/C CT103774
L1 IS POLYPHASE, C103555
CR1 & CR2 ARE 1N4942
Q1 & Q2 ARE 2N3421

Figure 7. DC-DC Converter, Schematic Diagram



NOTES:
1. COMPONENTS ENCLOSED BY DOTTED LINES ARE SHOWN FOR REFERENCE, THEY ARE PART OF 555154-1 (A3) ASSY. THE PART NUMBERS ARE AS FOLLOWS; R1 & R2 ARE REGOGR464, Q3 IS 2N 3501, Q4 IS 2N 4405, Q5 & Q7 ARE 2N3997 & Q6 IS 2N 5287.

Figure 8. Regulator-Temperature Control Circuits, Schematic Diagram

mounted at the GDO, which controls the circuit to maintain a constant GDO temperature over the ambient range. By supplying output transistors A1Q5 and A1Q6 from a separate lower voltage source than required by the control circuit, power losses are kept to a minimum. This arrangement assures that the total input current to the electronics will not exceed the 1-ampere requirement, regardless of input line voltage and ambient at startup.

6.4 ELECTROMAGNETIC COMPATIBILITY

In general, paramps usually are not significant interference sources. However, because of their sensitivity, care is required in the EMC design to obviate the possibility of susceptibility of the paramps. In particular the K_u-band paramp EMC design assures immunity to supply line noise and RF and magnetic interaction between co-located units. The amplifier system has been designed to meet the EMC requirements of MIL-STD-461A as amended for the Space Shuttle Program by SL-E-0002 and MIL-STD-462, Notices 1 and 2. In particular the K_u-band paramp system has been designed to meet the following requirements of MIL-STD-461A, as amended by SL-E-0002: CE01, CE03, CS01, CS02, CS06 and TT01.

The amplifier is contained within a shielded enclosure that protects the sensitive RF and bias circuits against the external electromagnetic environment. Within the same enclosure, all the components and the power supply necessary to provide a completely integrated paramp package that operates from a direct current input power source is included. The power lines are filtered with suitable feedthrough filters to protect the system against conducted interference and excessive emission.

In addition, the microwave components are isolated from the power supply, avoiding low frequency interference.

VII. CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

A completely integrated K_u-band Parametric Amplifier System, operating at a signal frequency of 13.775 GHz, has been developed for NASA Johnson Space Center, Houston, Texas, (Contract Number NAS 9-14586). The gain of the amplifier is 17 dB minimum over the 3-dB bandwidth of 50 MHz. The noise temperature of the system was measured as less than 120 K.

The K_u-band parametric amplifier system contains all of the necessary power supplies to operate from the 28 Vdc power supply of the vehicle, and drawing less than 1 A of current.

The parametric amplifier system was designed to operate in a space environment. The weight and volume of the unit were kept low, and the electronic components in the power supply have been chosen to adequately perform in a vacuum where proper heat sinking can present problems.

7.2 RECOMMENDATIONS

7.2.1 Further Weight Reduction

Although the weight of the K_u-band parametric amplifier system has already been reduced to 38.7 ounces (1097 grams), the following recommendations may further reduce the weight of the system:

a. The weight of the system housing and the RF component mounting plate can be reduced by one-third if magnesium is substituted for the aluminum used in their construction. This represents a weight saving of approximately 3.8 ounces (108 grams).

b. The circulator magnetic return yoke, which is made of steel, could be reduced in size to create a 0.42 ounce (12 gram) weight saving.

c. The RF input and RF output to the paramp system can be changed to coax instead of waveguide. This will eliminate the waveguide-to-coax transitions and their brackets for a weight reduction of 2.8 ounces (80 grams).

d. If the EMC requirements permit, the size and weight of the large input inductor can be reduced. Since this unit weighs 3.2 ounces (91.4 grams), a substantial savings may be achieved.

As can be seen the weight of the unit can be reduced by at least 7.05 ounces (200 grams).

7.2.2 Stabilization Temperature Power Reduction

The power required for temperature stabilization could be reduced by the use of electronic temperature compensation or the use of heat pipes as a means of thermal stabilization. The operating temperature of the paramp system would be increased from 39°C to 50°C, but the noise temperature of the unit would be degraded by only 4 K (from 116 K to 120 K).

7.2.3 Size Reduction

The size of the unit, which is 64.8 cubic inches (1061.4 cubic centimeters), could be further reduced with a redesign effort by standing the printed circuit boards on end. A size reduction of perhaps 11 cubic inches (180.3 cubic centimeters) is possible.